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September 8, 1964
Ref: 295/885-21/3865

National Aeronautics and Space Administration
400 Maryland Avenue, S.W.
Washington 25, D.C.

Attention: Dr. Michael Del Duca (Code RB)

Subject: Study of Biochemical Fuel Cells
under Contract No. NASw-654

Enclosures: (1) Eighteenth Monthly Letter Report,
"Study of Biochemical Fuel Cells"

(2) Distribution List for the Eighteenth Monthly
Letter Report, "Study of Biochemical Fuel Cells"

(3) Estimated Costs for Biochemical Fuel Cell
Program through August 28, 1964

1. Enclosure (1), describing the technical results of the work accomplished to date on this program, is hereby submitted in accordance with Article IV, Section A, of the subject contract.

2. Enclosures (2) and (3) indicate the distribution for Enclosure (1) and the estimated costs expended to date on the program in accordance with contract requirements.

THE MARQUARDT CORPORATION

Thomas G. Bek

Thomas G. Bek, Manager
Van Nuys Contract
Administration Section

TGB:GEE:db

Enclosure 1
LR 295-18

Sept., 1964

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National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D. C.

Attention: AFSS-A

Eighteenth Monthly Letter Report

1 August 1964 to 1 September 1964

STUDY OF BIOCHEMICAL FUEL CELLS
Contract NASw-654

The Marquardt Corporation, ASTRO Division
16555 Saticoy Street
Van Nuys, California

Telephone 781-2121 (Area Code 213)
George E. Ellis, Principal Investigator

During the past month, investigations have been conducted on the subject contract under the following general topics:

(1) Effect of total time in the system vs. cell time, maintaining a given ratio of electrode area:fuel-anolyte volume in both the flow and non-flow systems;

(2) Electrochemical activity of Escherichia coli on an amino acid indigenous to human waste;

(3) Electrochemical degradation of activated sludge; and

(4) Effect of bubbling pure hydrogen gas into a feces-urine mixture.

I EFFECT OF TOTAL TIME IN THE SYSTEM VS. CELL TIME

Further experiments are being conducted to determine the effects of chemical-biochemical reactions in comparison with chemical-biochemical-electrochemical reactions. The chemical-biochemical reactions occur independently of electrodes, while the chemical-biochemical-electrochemical reactions occur in the proximity of the electrodes.

It is appropriate at this time to redefine the terms. "Total time" refers to the elapsed time since the fuel-anolyte was mixed and introduced into the biofuel cell system; "cell time" refers to the total amount of time spent by the fuel-anolyte in the proximity of the electrodes. In the case of the non-flow system, cell time equals total time, whereas in the flow system, the ratio of cell time:total time is equal to the ratio of cell volume:total volume.

The experiment is being conducted in the flow and non-flow systems under the experimental conditions described in Table I.

It was found in earlier studies that there was no direct correlation between the anodic open-circuit potentials of the two systems as a function of time on either a total time or a cell time basis.

The specific purpose of this experiment is to determine the effect of maintaining the same ratio of electrode surface to fuel-anolyte volume in both systems; the details are tabulated below:

System	Electrode Area (sq. in.)	Fuel-Anolyte Volume (ml.)	Ratio of Electrode Area to Fuel-Anolyte Volume
Flow	3.54	300	.0118
Non-flow	1.00	85	.0118

II ELECTROCHEMICAL ACTIVITY OF ESCHERICHIA COLI ON AN AMINO ACID

A limited effort is being expended in determining some of the reaction mechanisms associated with chemical and electrochemical degradation of human waste. The basic plan is to determine rather simply whether one or two of the many types of microorganisms indigenous to

human waste may be responsible for producing most of the electrochemical power that is obtainable from human waste, by preferential metabolic reactions involving one or two of the indigenous chemical compounds.

A list of chemicals indigenous to human feces was presented in the thirteenth monthly report.

Carbohydrates, lipids, and proteins are present in human waste. The initial study involves determining the electrochemical energy output caused by the metabolic reaction of one of the indigenous microorganisms (Escherichia coli) on one of the amino acids that constitute the protein content of human feces.

The experiment is being conducted under the conditions described in Table I for the non-flow system, except that the fuel-anolyte will contain only an amino acid (arginine, lysine, or threonine) in sterile, deionized water. The length of time required for this experiment is expected to be very short (e.g., a few hours), because it is recognized that the small amount of amino acid being used in this experiment (approximately 1/6 gm.) will be quickly consumed, and further that a medium containing only water and one additional chemical compound (the amino acid) is not a satisfactory nutrient for continued microbiological metabolism.

III ELECTROCHEMICAL DEGRADATION OF ACTIVATED SLUDGE

A sample of activated sludge was obtained from a local sewage treating plant (courtesy Mr. Joseph Nagano, Hyperion Sewage Works, Playa del Rey, California).

This material is being maintained in an aerated, viable condition by bubbling with gaseous oxygen and by periodically adding fresh human waste to the sludge.

The sludge is being used under experimental conditions similar to those described in Table I for the non-flow system, except that activated sludge was added to the urine-feces mixture in a final volume ratio of 1 volume of activated sludge to 9 volumes of the usual urine-feces mixture, and the fuel-anolyte is being aerated.

A galvanostat is being used to control the current input to the biofuel cell, in order to evaluate the extent of degradation of human waste by electrochemical energy.

Another experiment is being conducted with the activated sludge, under the same experimental conditions as those described above, but at 97°F (body temperature) instead of at room temperature (76°F).

IV EFFECT OF BUBBLING PURE HYDROGEN GAS INTO A FECES-BRINE MIXTURE

An experiment is being conducted, in which the experimental conditions are the same as those described in Table I, except that pure, gaseous hydrogen is bubbled into the fuel-anolyte instead of helium. The purpose of this experiment is to determine the electrical power output obtainable if hydrogen, which is one of the products of the degradation of human feces, is present in excess; that is, if the availability of hydrogen is not limited by metabolic reactions.

It is not contemplated that pure, gaseous hydrogen would be used in a biofuel cell in a space system employing human waste as the fuel. The purpose of the experiment was to determine the power level of the system if a considerable amount of hydrogen had accumulated for a period of time in the space vehicle, due to degradation of the waste. This experiment removes the metabolic production of hydrogen as the rate-limiting step in the production of electrical power from human waste.

The results of the experiment are tabulated below:

Run No.	83
Peak Anodic Power Density (mw/sq. ft.)	3.42
Peak Total Power Density (mw/sq. ft.)	3.42
Short Circuit Current Density (ma/sq. ft.)	34.5
Open-Circuit Anodic Potential at Time of Polarization Study (volt)	-0.669
Best Anodic Open-Circuit Potential (volt)	
pH, Initial	8.7
pH, Final	

The effects of other pure gases which are normally produced during the degradation of human waste (e.g., hydrogen sulfide, ammonia) will be determined, if time permits, insofar as they effect the power output of a biochemical fuel cell. Again, as in the case of the hydrogen experiment described above, the pure gas will be present in excess, as though accumulated in a biofuel cell over a period of time, and metabolic production of the gas will not be rate-limiting.

FUTURE WORK

During the next month, investigations will be conducted in the following areas:

1. Completion of the studies described in this report; and
2. Determination of the extent of metabolism of carbohydrate by E. coli.
3. Issuance of the final report covering the investigations under this contract.

Prepared by:

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Approved by:

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TABLE I

EXPERIMENTAL CONDITIONS
BIOCHEMICAL FUEL CELL

FLOW SYSTEM

Cell: Plastic (Lucite)

Electrodes: Platinized platinum foil, 2-1/8 in. clear diameter, 3.54 sq. in. geometric area.

Separator: Cellulose acetate (Sargent S-14825, 0.001 in. thick).

O-Rings: Silicone (Dow Corning S-7180).

Catholyte: 2½ wt. % NaCl - 2½% KCl in sterile, deionized water; non-biological; bubbled with purified, gaseous oxygen.

Waterproof and Chemically Resistant Paint: Temprotec TP 220 Red (Ryan Herco Products Corp., Burbank, California).

Fuel-Anolyte: 30 gms. non-sterile, human feces (special diet; frozen and thawed) in 100 ml. non-sterile, human urine (frozen and reheated to 120°F). Feces was obtained from volunteers on a low cellulose diet, and was frozen immediately after collection. Homogenized in Osterizer Deluxe (John Oster Mfg. Co., Milwaukee). Bubbled with helium.

NON-FLOW SYSTEM

Cell: Glass, H-Shape, O-Ring type

Electrodes: Platinized platinum foil, 1 sq. in. area (non-opposing faces coated with waterproof and chemically resistant paint).

Separator, O-Rings, Catholyte, Fuel-Anolyte, and Waterproof and Chemically Resistant Paint: Same as for flow system.

DISTRIBUTION LIST

FOR THE SEVENTEENTH MONTHLY LETTER REPORT,

"STUDY OF BIOCHEMICAL FUEL CELLS"

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ESTIMATED COSTS

OF BIOCHEMICAL FUEL CELL PROGRAM

THROUGH AUGUST 28, 1964

Engineering Hours Expended	5,482
Technician Hours Expended	671
Estimated Cost	$76,255
Commitments	77